International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 10, Issue 2, Apr 2020, 1053–1062

APPLICATION OF LASER IMPLANTATION FOR INCREASING IMPACT RESISTANCE OF ALUMINUM PARTS

LEV BALDAEV[1], IVAN MAZILIN[2], SERGEY MERCHEV[3] & ANTON MATSAEV[4]

[1]*Doctor of Engineering Sciences, "Technological systems of Protective Coatings", Simferopol'skoe, Sherbinka, Moscow region, Russia*

[2]*Candidate of Engineering Sciences, "Technological Systems of Protective Coatings", Simferopol'skoe, Sherbinka, Moscow region, Russia*

[3,4]*Limited Liability Company, "Technological Systems of Protective Coatings", Simferopol'skoe, Sherbinka, Moscow Region, Russia*

ABSTRACT

Aluminium is known to have lightweight, good corrosion sustainability and perfect abilities to be recycled. Combination of these benefits attracts engineers to apply aluminium more and more. Among main disadvantages of aluminium are low hardness and plasticity. This lack of strength creates limitations for applying aluminum alloys in high loaded construction. There are known many techniques for providing strength properties for aluminum parts, among which Laser implantation is one of the most promising. Opportunity of building impact-proof surfaces on aluminum alloy parts was investigated in this article. To achieve processability for aluminum alloys, surfacing technic $TiB_2TiCMoSiO_2$ powder materials were used. Special rigging for IATS lever laser treatment was developed. Three impact protected aluminum alloys prototypes were produced.

***KEYWORDS:** Laser Implantation, Aluminum Alloy Hardening, Impact Resistance, Face-Hardening & Laser Technologies*

Received: Feb 23, 2020; **Accepted:** Mar 13, 2020; **Published:** Apr 04, 2020; **Paper Id.:** IJMPERDAPR2020102

Original Article

1. INTRODUCTION

Aluminium [1] is one among light metals, which is technically interesting because of its availability, cost and machinability. However, aluminium does not have sufficient surface strength, which can be provided by various hardening technologies.

The papers [2-5] study the processes of laser cladding of ceramic particles on aluminium, and in [6-8] there are presented the achievements in the field of laser implantation of various particles in the surface layer of aluminum base in order to achieve unique mechanical properties.

The aim of this work is to develop an aluminum Inertial Automatic Train Stops (IATS) lever with improved strength characteristics by the laser implantation technologies. IATS are designated for emergency stop of train which speed exceeds the acceptable value. Conventional IATS designed from steels (primarily Cт20) are approved for safety systems with breaks activating at the speed level of 15 km/h.

Saint Petersburg metro traffic increase leads to necessity of organizing train movement with higher average speed. That is why the new IATS activating speed levels (between 20 and 30 km/h) were to be achieved. These tasks put requirements for IATS lever to be much lighter than conventional levers made of constructing steels.

When train speed exceeds the activating level the impact strength is enough for breakdown valve actuation due to contact with IATS lever, which construction presents mechanical pendulum. The activating speed level depends on lever's inertia level.

To meet Russian regulatory requirements, Technical Maintenance Rules (TMR) IATS must be installed 85+5 mm higher than top of the rails while the train's breakdown valve bracket is installed at the level among 52 to 55mm higher than the top of the rail. The distance between the center of IATS lever and the inner surface of the nearest rail is 308±20 mm.

Conventional steel lever has moment of inertia 22800 kg*mm^2. To achieve the activating speed, the moment of inertia must be decreased. Since current regulatory rules strictly limit the geometrical dimension for levers, the best way to achieve desired level of activating speed is to decrease the weight of lever.

2. CHOICE OF MATERIAL FOR LASER IMPLANTATION

The chemical composition of the used material is presented in the Table 1. It was supplied by Energohimkomplekt. Visual control for morphology determination was performed on Zwick/Roell ZHVμ-AF microscope. Delta Series ITS was used for x-ray fluorescence chemical analysis. Before performing fraction inspection tests materials, the material probe with250 grams weight has been heat treated in «SHS-80-01» drying setup (100 °C for 30 minutes). Further, it classified with set of meshes (20to 200 μm).

Table 1: $TiB_2TiCMoSiO_2$ Powder Chemical Composition

Ti	Si	Mo
67,43	1,60	27,84

Scanning electron microscope (SEM) analysis was carried out with JSM 6490 LV scanning microscope. The powder morphology was inspected and presents the set of irregular shape particles with size between 0 to 100 microns. The study results study is shown on Figure 1.

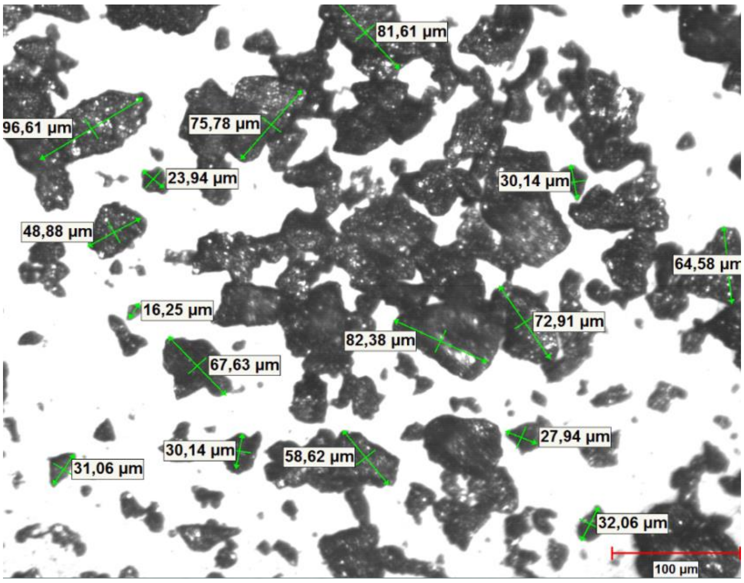

Figure 1: Powder Morphology.

The irregularity of particles shape may be explained by the manufacturing specific where the raw material is

crushed. Particle distribution was determined by sieve analysis [9]. Haver Boecker EML 200 digital T Vibration stand with set of sorted by size meshes. Bulk density was tested in accordance to [10]. Set of probes with volume 25 cm^3 was weighed. Powder flow ability was investigated in accordance with [11]. The time for 50grams of powder passing through standard funnel with specified aperture was measured for the set of probes. The results for bulk density and flow ability tests are presents in the Table 2, particle distribution test result is presented in the table 3. Due to low density and irregular crushed shape of particles, the flow ability tests failed to provide the correct value the flow ability property.

Table 2: Powder Physical Properties

Flowability, sec/50 g	Bulk density, g/cm^3
n/d	3,40

Table 3: Particles Size Distribution

Fraction	Mesh rest, g	Mesh rest, %	Passer through mesh, g	Passed through mesh, %
53	3,74	3,80	94,54	96,20
45	25,90	26,35	68,64	69,85
36	27,48	27,96	41,16	41,89
20	31,08	31,62	10,08	10,27
<20	10,08	10,27	-	-

3. LASER IMPLANTATION PROCEDURE

LDF-6000 laser line with 6kW power of diode source, Coax optical system with 6-ports powder feeding system installed on Kuka KR-60 robotical system with additional turntable system were used for aluminum parts surfacing.

A diode laser source was selected because of the wavelength of less than 1 µm. At such a value, the absorption coefficient of the aluminum substrate significantly exceeds the absorption coefficient of fiber and CO_2 lasers [12].

The set of D16T (aluminum alloy) testaments were processed before IATS lever were produced. Aluminum alloy D16 is a high-strength duralumin of the A1-Cu-Mg system with ligating manganese additives. In hardness and mechanical strength, it is not inferior to steel, but, unlike it, has 3 times lighter specific weight. Table 5 shows the chemical composition of D16T aluminum alloy.

Table 4: Chemical Composition of D16T Aluminum Alloy

Fe	Si	Mn	Cr	Ti	Al	Cu	Mg	Zn
0.5	0.5	0.3-0.9	0.1	0.15	90.9-94.7	3.8-4.9	1.2-1.8	0.25

The special technological equipment rigging was designed and used to provide uniform scanning of the lever's surface. It is presented on the Figure 2.

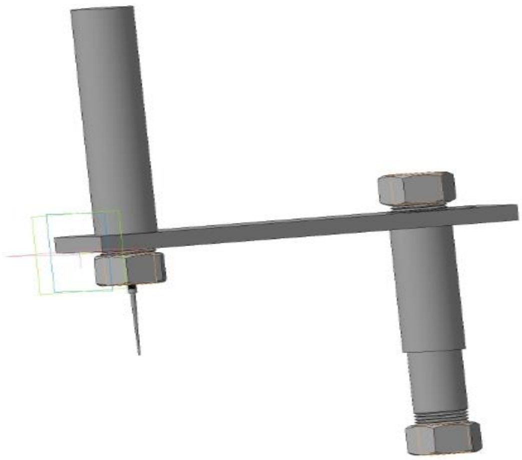

Figure 2: Technological Equipment for IATS Lever Laser Treatment.

Before laser implantation, the surface was sandblasted to clean the surface from dirt and increase the absorption coefficient of aluminum alloy for diode laser wavelength. In the Table 5, there is presented data for technological parameters of D16T surface laser implantation adjustment.

Table 5: Technological Parameters for Laser Implantation

Amount of passes	Radiation power, W	Scanning speed, m/sec	Passes intersection ration, %	Transportation gas flow, l/min	Shield gas flow, l/min	Powder feeding, rpm
1	1000	0,01	50	5	20	0,3
2	1500	0,01	50	5	20	0,3
3	1500	0,0125	50	5	20	0,3
4	2000	0,0125	50	7	50	0,5
5	2000	0,015	50	7	50	0,5

Mode No. 4 (four amount of passes) was selected as the main after testaments SEM analysis. It was described as the one with relatively homogeneous carbides distribution in the layer.

Three experimental IATS levers were processed. The weight of implanted powder is about 30grams. Total powder amount used for hard facing is 180 g. Powders efficiency is about 50%. The processing duration is 38 min. per item. On the Figure 3 there is presented view of processed lever.

Figure 3: IATS Laser after Laser Processing.

4. Coating Parameters

For laser implanted surface quality evaluation (thickness, micro hardness, morphology, porosity and so on) the processed testaments were investigated. Cross sections in accordance with were prepared for microstructure analysis. Analysis was carried out on Axiovert 40 MAT (Germany). The view of implanted coating is presented on the figure 4.

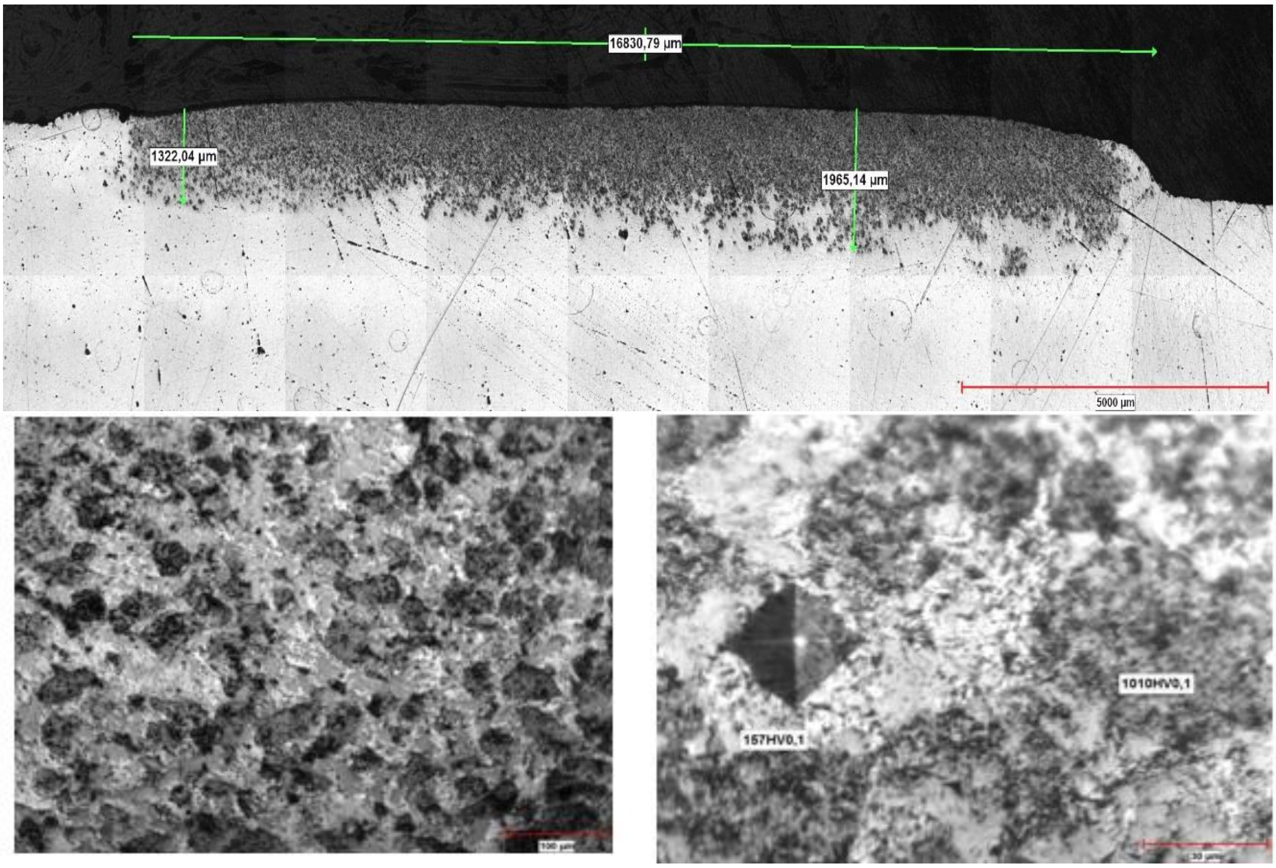

Figure 4: Metallographic Analysis of Hardened with $TiB_2TiCMoSiO_2$ D16T testaments

The following parameters for investigated samples were determined: thickness varies from 1.3 to 2.0 mm., micro hardness is from 140 HV0.1 to 1300 HV0.1, even distribution of hard carbides particles, porosity is less than 0.3%, no cracks, delamination, contaminations were found.

Microprobe elemental analysis of the coating after laser implantation was performed using the AZtec X-MAX energy dispersion spectrometer (Oxford Instruments). The obtained results of microprobe elemental analysis were arranged by the study zones: implantation zone (IZ), thermal influence zone (TIZ), base.

The study of the implantation zone was carried out in the epicenter of the laser band (1) and on the periphery (2), as well as integrally (3) over the entire section of the AI. Schematically, the study areas are shown in Figure 5.

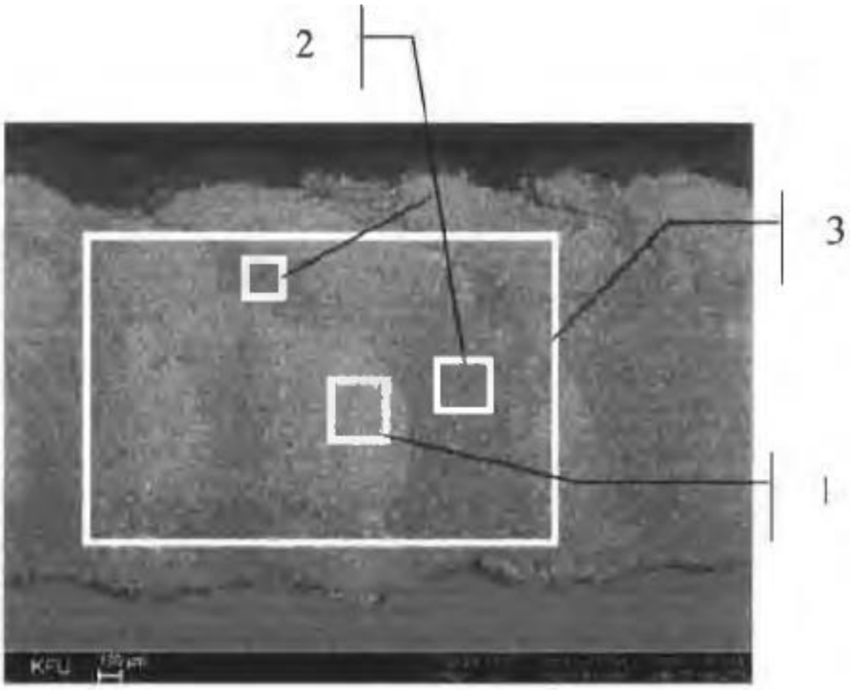

Figure 5: Scheme of the Study Laser Implantation Zone.

Thus, the elemental composition by study areas is presented in Table 6.

Table 6: Elemental Composition

Chemical elements	B	C	Mg	Al	Si	Ti	Mn	Fe	Mo	Cu
Implantation zone	10,2	12,5	0,5	32,9	4,2	23,6	0,3	0,3	8,6	1,8
Thermal influence zone	-	5,0	1,3	86,0	0,4	1,2	0,5	0,2	-	4,4
Base	-	4,8	1,2	87,4	0,2	-	0,6	0,2	-	4,3

The chemical composition of the implantation zone contains both elements of the base metal and elements of the implanted powder. The zone formed as a result of laser implantation is heterogeneous in structure and is characterized by a picture of alternating strips of compact location of the implanted particles (epicenter) and space between the strips (periphery). The elemental composition of the epicenter of the band and the periphery is different (Table 7).

Table 7: Elemental Composition

Chemical elements	B	C	Mg	Al	Si	Ti	Mn	Fe	Cu	Mo
Laser band epicenter	6,9	13,4	0,3	17,7	9,6	30,0	0,2	1,0	1,1	14,6
Periphery	9,2	14,5	0,6	46,3	1,9	15,2	0,3	0,4	2,4	4,1

The zone of thermal influence on the chemical composition is practically similar to the base, except for the presence of insignificant amounts of titanium. A study of the internal structure of the implantation zone showed the following. The microstructure of the laser implantation layer is a matrix with clusters of dispersed particles located in it. The sizes of the compacts are related to the sizes of the initial agglomerated particles of the implanted powder. In the inner layers of the implantation zone, the compacts were mainly broken up into separate particles. The particles included in the compact are mainly small, rounded and lamellar particles with sizes of about 2.5-10 µm and 13-20 µm, respectively. Flow microanalysis and mapping of such compacts showed that the small particles of rounded shape included in their composition are particles with elemental compositions of Ti-B, Ti-C, Ti-B-C-Mo, small particles of lamellar shape - Ti-C-Mo. There are large lamellar particles with sizes up to 45 - 50 µm, having elemental composition Mo-Si-Ti-C-B, Mo-Si-Al.

5. IATS LEVERS PRODUCTIONS AND TESTS

The Saint-Petersburg metro system had been supplied by 2 experimental IATS levers for natural tests operating. During all test stages, the surfaced area has no critical comments. After counterweights system adjustment had been performed the IATS achieved 26 km/h as the speed of activating. For security reasons the Committee for Safety Operation recommended the application of new IATS at the speed activating level of 23 km/h. During tests, the commission has formed the recommendations for strengthening mounting point to increase IATS reliability. The new IATS construction was accepted for operation in Saint-Petersburg metro. The common view of IATS lever mounted on support is presented on the fig. 5.

Figure 5: Aluminum Alloy IATS Lever.

6. DISCUSSIONS

The investigation proved that laser technologies may be used for creating impact-proof surfaces on aluminum alloys parts. Laser implantation is able to harden aluminum surfaces and may be applied for lightweight impact proof solutions with sufficient powder efficiency. $TiB_2TiCMoSiO_2$ layer provides high level of hardness, up to 1300 HV0.1. The thickness of hardened layer is from 1.3to 2.0 mm.

In addition, ceramic laser implantation can now be distinguished as the only technology for hardening the surface of aluminum parts, providing maximum performance, full automation and excellent mechanical properties of the product in continuous operation in real conditions. Traditional processes of parts surface hardening by methods of argon-arc cladding and plasma cladding have a significant drawback in the form of the fact that the amount of heat introduced into the processing zone can lead to deformation of the part and formation of cracks on its surface.

7. CONCLUSIONS

On the basis of the study, the following results were obtained. Laser implantation technologies may be effectively used for projecting lightweight constructions with impact proof properties. Opportunity of building impact-proof surfaces of aluminum alloy parts was investigated in this article. To achieve processability for aluminum alloys surfacing technic $TiB_2TiCMoSiO_2$ powder materials was used. This powder material has been comprehensively studied to determine the chemical composition, morphology, physical properties and fractional composition. Despite the crushed shape of the powder particles and the extremely low fluidity, it was possible to achieve a constant flow of the material into the melt bath by

providing a stable transport of argon to the nozzle of the optical system. However, microprobe elemental analysis of the coating after laser implantation showed different elemental composition in the implantation zone. For a uniform powder flow, it is necessary to use a powder with a spherical shape of a larger fraction.

Optimal technological parameters of laser implantation with the radiation power of 2000 W, scanning speed 0,0125 m/sec, passes intersection ration 50 %, transportation gas flow 7 l/min, shield gas flow 50 l/min, powder feeding 0,5 rpm were selected. Microhardness of IATS lever surfaces increased up to 1300 HV0.1.

IATS lever passed 1.5 year natural tests and is has been accepted after for operation in Saint Petersburg metro system. Hardened surface also has sufficient values for friction coefficient and may be applied in friction pairs, but additional tests are required.

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